Supporting Information

for

Determinants of Greenhouse Gas Emissions from Interconnected Grids in China

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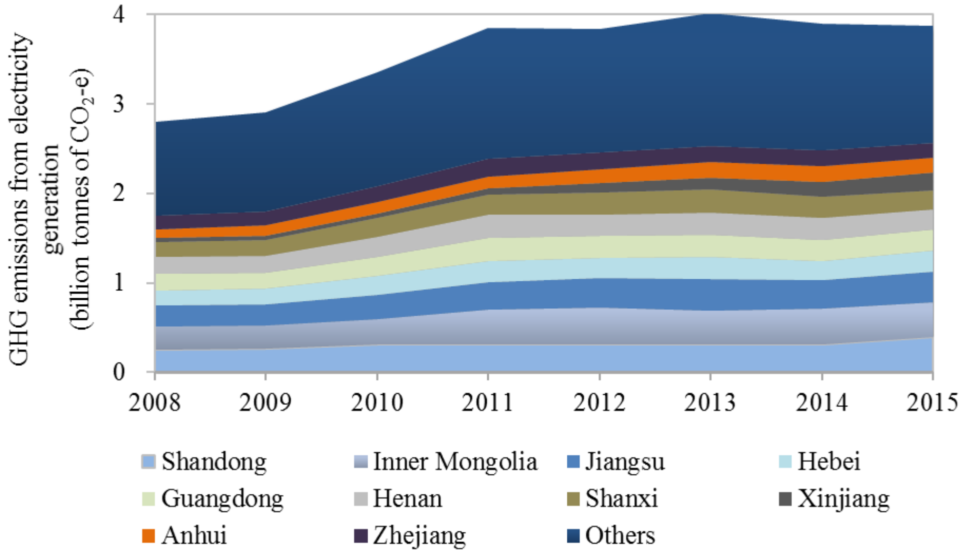
The supporting information provides the results of the QIO model and supplemental Tables supporting the main text.

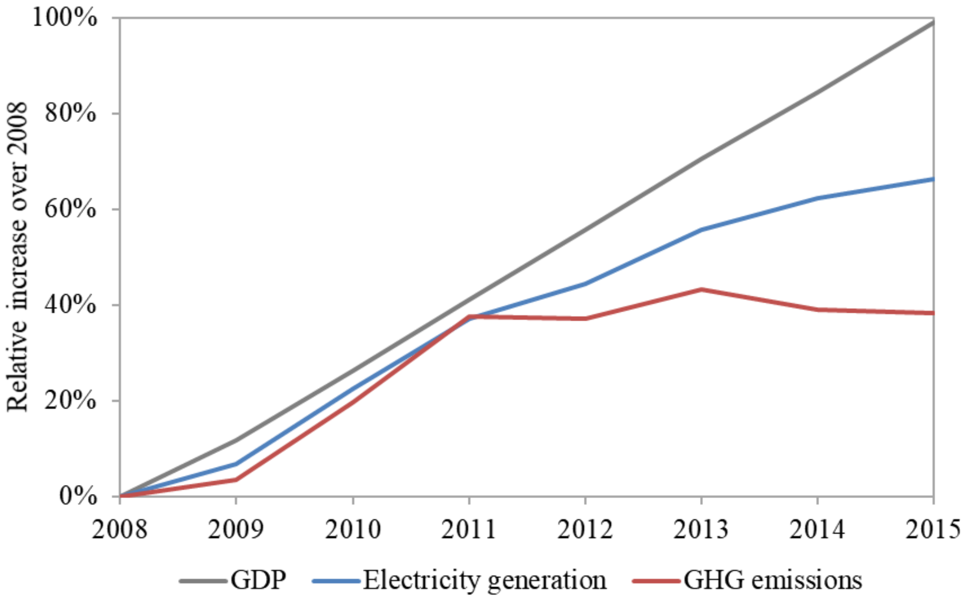
S1 GHG Emissions from Electricity Generation

GHG emissions from electricity generation generally increased from 2.8 billion (10^9) tonnes (Bt) of CO_2 equivalents (CO_2-e) to 3.9 Bt during 2008–2015 (Figure S1a). The top 10 grids with the largest power generation (Figure S1a) contributed about 60% of the total electricity generation in China. Shandong and Inner Mongolia are the two largest electricity producers, contributing 10.2% and 10.1% of total electricity generation in 2015, respectively.

China implemented the *Four-Thousand-Billion Stimulus Plan* in 2008 for economic rehabilitation after the global financial crisis. This facilitated the rapid increase in GDP, electricity generation, and GHG emissions during 2009–2011 (Figure S1b). We observed two decoupling trends after 2011: the decoupling of GHG emissions from electricity generation and GDP; and the decoupling of electricity generation from GDP.



(a) GHG emissions from electricity generation



(b) Changes in GDP, electricity generation volume, and associated GHG emissions

Figure S1. GDP, electricity generation volume, and associated GHG emissions during 2008–2015. Full results are listed in Tables S1 and S2 in the Supporting Information (SI).

S2 GHG Emissions caused by Electricity Consumption

Figure S2a compares GHG emissions from electricity generation (generation-based GHG emissions) with those caused by electricity consumption (consumption-based GHG emissions) in 2015. We observed obvious differences between generation-based and consumption-based GHG emissions, which are caused by inter-grid electricity transmission.

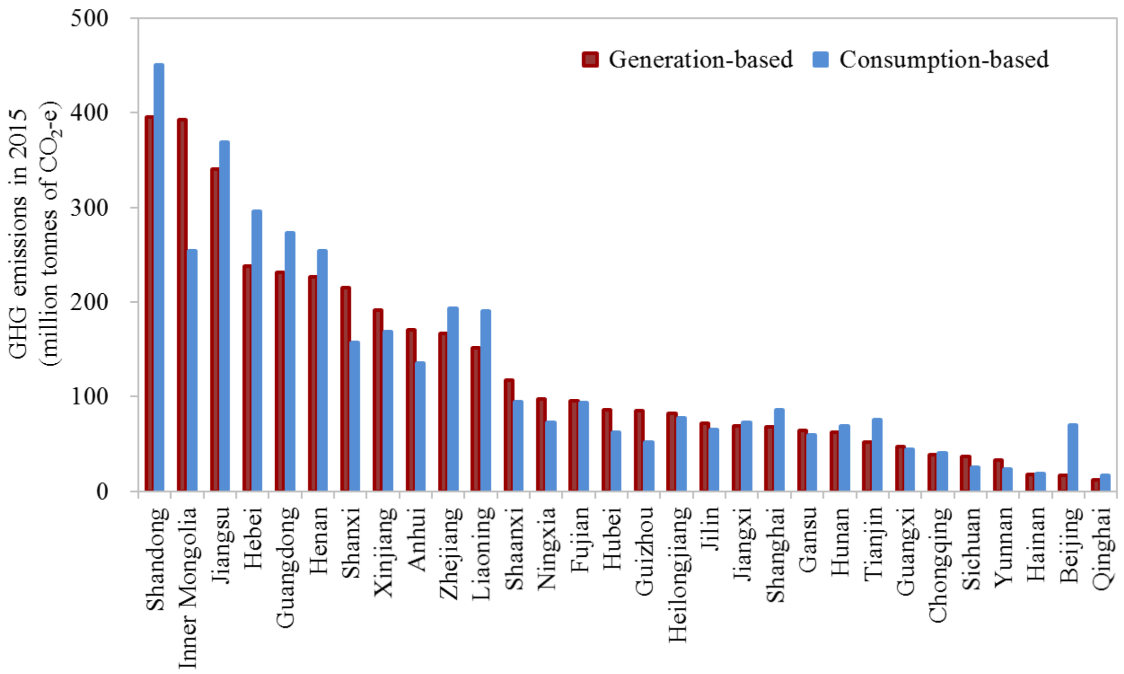
Net electricity importing provinces such as Shandong, Jiangsu, Hebei, Guangdong, Henan, Zhejiang, and Liaoning have larger consumption-based GHG emissions than generation-based GHG emissions. For example, consumption-based GHG emission in Hebei and Liaoning are 24% and 25% higher than their generation-based GHG emissions, respectively, in 2015. We observed the same situation for 4 municipalities including Shanghai, Tianjin, Beijing, and Chongqing. Consumption-based GHG emissions in Beijing are around four times larger than its generation-based GHG emissions. For Shanghai and Tianjin, their consumption-based GHG emissions are 27% and 46% higher than generation-based GHG emissions in 2015.

In contrast, net electricity exporting provinces such as Inner Mongolia, Shanxi, Xinjiang, and Anhui have larger generation-based GHG emissions than consumption-based GHG emissions. For example, generation-based GHG emissions of Inner Mongolia and Shanxi are 54% and 37% higher than their consumption-based GHG emissions in 2015. These provinces are major electricity exporters to other regions in China.

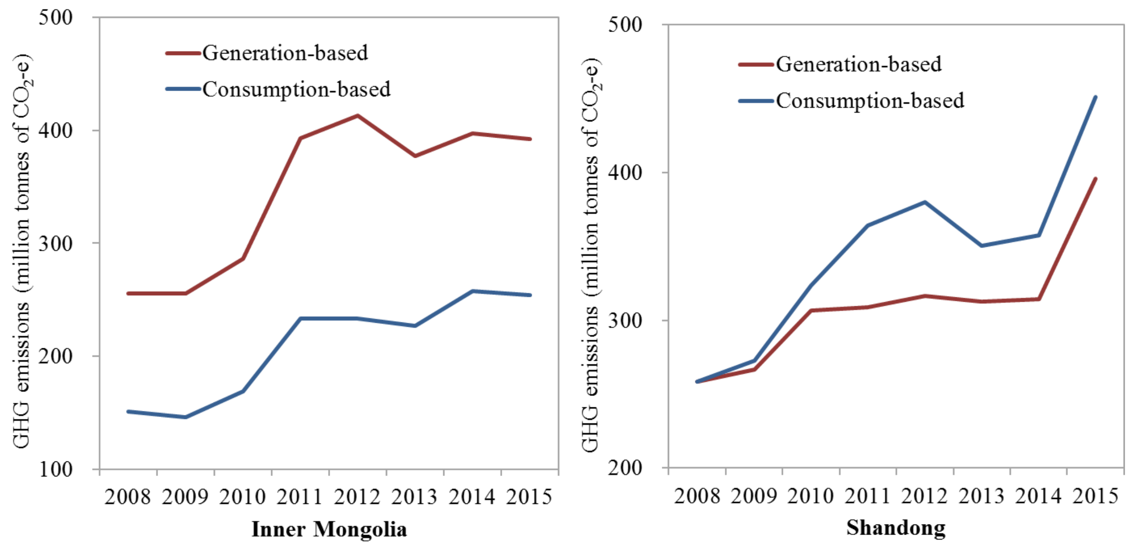
We specifically investigated the differences between generation-based and consumption-based GHG emissions in Inner Mongolia and Shandong – two largest grids in electricity generation (Figure S2b). Generation-based and consumption-based GHG emissions in Inner Mongolia and Shandong showed generally increasing trends during 2008–2015, with slight decreases during 2012–2013. There have been obvious differences between generation-based and consumption-based GHG emissions in Inner Mongolia and Shandong during 2008–2015, especially during 2011–2013.

We further revealed consumption-generation pairs to show which electricity consumers are driving GHG emissions from electricity generation of a particular grid. For instance, Inner Mongolia in Northeast China is the largest electricity producer and exporter, and GHG emissions from its electricity generation increased by 137 million tonnes of CO_2-e during 2008–2015. Major consumers driving GHG emissions from electricity generation in Inner Mongolia include Liaoning, Beijing, Shanxi, and Tianjin, contributing 15%, 8%, 4%, and 2% to this increase, respectively. These provinces are major importers of electricity generation in Inner Mongolia. Moreover, Shanxi in North China is also a large electricity producer and exporter. The increase in its generation-based GHG emissions during 2008–2015 is mainly driven by the growth in electricity consumption of Hebei (contributing 28%), Henan (10%), and Shandong (7%).

The above findings indicate the necessity to investigate GHG emissions embodied in inter-grid electricity flows. Generation-based results can identify “hotspots” grids for production-side measures such as using low-carbon energy sources and improving thermal efficiency of power generation. Consumption-based results can identify “hotspots” grids for consumption-side measures such as improving electricity end-use efficiency.



(a) Generation-based and consumption-based GHG emissions in 2015



(b) GHG emissions of Inner Mongolia and Shandong grids during 2008–2015

Figure S2. Generation-based and consumption-based GHG emissions of each grid in China. Full results are listed in Tables S3 in the SI.

S3 Additional Tables Supporting the Main Text

Table S1. GHG emissions from electricity generation during 2008–2015 (Unit: billion tonnes of CO_2-e).

Provincial grids	2008	2009	2010	2011	2012	2013	2014	2015
Beijing	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Tianjin	0.04	0.04	0.05	0.06	0.06	0.06	0.05	0.05
Hebei	0.17	0.18	0.21	0.24	0.23	0.25	0.22	0.24
Shanxi	0.17	0.17	0.22	0.24	0.25	0.25	0.24	0.22
Inner Mongolia	0.26	0.26	0.29	0.39	0.41	0.38	0.40	0.39
Liaoning	0.11	0.12	0.14	0.15	0.15	0.15	0.16	0.15
Jilin	0.07	0.06	0.06	0.08	0.07	0.07	0.08	0.07
Heilongjiang	0.08	0.08	0.08	0.09	0.09	0.07	0.08	0.08
Shanghai	0.07	0.07	0.08	0.08	0.07	0.08	0.07	0.07
Jiangsu	0.24	0.23	0.27	0.31	0.33	0.35	0.32	0.34
Zhejiang	0.15	0.16	0.17	0.19	0.18	0.18	0.17	0.17
Anhui	0.10	0.12	0.13	0.13	0.16	0.18	0.18	0.17
Fujian	0.07	0.07	0.07	0.11	0.10	0.11	0.11	0.10
Jiangxi	0.04	0.05	0.06	0.06	0.06	0.07	0.07	0.07
Shandong	0.26	0.27	0.31	0.31	0.32	0.31	0.31	0.40
Henan	0.19	0.19	0.22	0.25	0.24	0.25	0.24	0.23
Hubei	0.06	0.06	0.08	0.10	0.08	0.09	0.09	0.09
Hunan	0.05	0.06	0.07	0.09	0.07	0.08	0.07	0.06
Guangdong	0.19	0.18	0.22	0.26	0.24	0.25	0.24	0.23
Guangxi	0.03	0.04	0.05	0.06	0.06	0.07	0.06	0.05
Hainan	0.01	0.01	0.01	0.01	0.02	0.02	0.02	0.02
Chongqing	0.03	0.03	0.03	0.04	0.04	0.05	0.04	0.04
Sichuan	0.06	0.06	0.06	0.06	0.06	0.07	0.06	0.04
Guizhou	0.08	0.10	0.10	0.10	0.10	0.10	0.09	0.08
Yunnan	0.06	0.07	0.07	0.08	0.07	0.06	0.05	0.03
Shaanxi	0.07	0.08	0.10	0.10	0.10	0.11	0.12	0.12
Gansu	0.04	0.04	0.06	0.07	0.07	0.07	0.07	0.06
Qinghai	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Ningxia	0.05	0.05	0.06	0.10	0.10	0.10	0.10	0.10
Xinjiang	0.04	0.05	0.05	0.07	0.10	0.13	0.17	0.19

Table S2. Changes in GDP, electricity generation volume, and associated GHG emissions during 2008–2015.

Year	GDP changes	Electricity generation changes	GHG emission changes
2008	-	-	-
2009	12%	7%	4%
2010	26%	23%	20%
2011	41%	37%	38%
2012	56%	45%	37%
2013	70%	56%	43%
2014	85%	62%	39%
2015	99%	66%	38%

Table S3(a). Generation-based and consumption-based GHG emissions of each grid in China in 2015 (Unit: million tonnes of CO_2-e).

Provincial grids	**Generation-based**	**consumption-based**
Shandong	396	451
Inner Mongolia	393	254
Jiangsu	340	369
Hebei	238	296
Guangdong	231	273
Henan	226	254
Shanxi	216	157
Xinjiang	191	169
Anhui	170	135
Zhejiang	167	194
Liaoning	152	191
Shaanxi	117	95
Ningxia	98	73
Fujian	95	94
Hubei	86	63
Guizhou	85	51
Heilongjiang	82	77
Jilin	71	65
Jiangxi	69	73
Shanghai	68	86
Gansu	64	59
Hunan	62	69
Tianjin	52	75
Guangxi	47	44
Chongqing	39	41
Sichuan	37	25
Yunnan	33	23
Hainan	18	19
Beijing	17	69
Qinghai	12	17

Table S3(b). GHG emissions of Inner Mongolia and Shandong grids during 2008–2015 (Unit: million tonnes of CO_2-e).

Year	**Inner Mongolia**		**Shandong**	
	Generation-based	**Consumption-based**	**Generation-based**	**Consumption-based**
2008	255	151	258	258
2009	256	146	267	273
2010	287	169	307	324
2011	393	234	309	364
2012	413	233	317	380
2013	377	227	313	350
2014	397	258	314	357
2015	393	254	396	451

Table S4. Relative contributions of six factors to changes in GHG emissions from interconnected grids of China during 2008–2015 (Unit: million tonnes of CO_2-e).

Decomposed factors	2008-2009	2009-2010	2010-2011	2011-2012	2012-2013	2013-2014	2014-2015	2008-2015
GDP	311	382	402	377	352	308	283	**2416**
Fuel mix	-19	201	-27	4	49	-43	10	**174**
Electricity transmission structure	0	1	16	-14	-13	-39	-10	**-58**
Electricity structure	28	-40	55	-155	1	-109	-103	**-323**
Energy efficiency	-91	-141	55	-44	-156	-89	-23	**-488**
Electricity efficiency of GDP	-130	45	-2	-176	-62	-145	-178	**-648**
Total changes	**100**	**449**	**500**	**-9**	**171**	**-118**	**-21**	**1071**

Table S5. The sub-national and provincial grids of China.

Sub-national grids	**Provincial grids**
North China Grid	Beijing
	Tianjin
	Hebei
	Shanxi
	Shandong
East China Grid	Shanghai
	Jiangsu
	Zhejiang
	Anhui
	Fujian
Central China Grid	Jiangxi
	Henan
	Hubei
	Hunan
	Chongqing
	Sichuan
Northeast China Grid	Inner Mongolia
	Liaoning
	Jilin
	Heilongjiang
Northwest China Grid	Shaanxi
	Gansu
	Qinghai
	Ningxia
	Xinjiang
Southern Power Grid	Guangdong
	Guangxi
	Hainan
	Guizhou
	Yunnan

Notes:

Tibet grid belonging to the Northwest China Grid is not included in this study due to data unavailability.

Table S6. GHG emissions caused by electricity consumption of sub-national grids in China during 2008–2015 (Unit: million tonnes of CO_2-e).

Year	North China Grid	East China Grid	Central China Grid	Northeast China Grid	Northwest China Grid	Southern Power Grid
2008	719	647	422	433	207	364
2009	744	676	435	427	216	393
2010	888	759	515	478	252	448
2011	992	852	602	591	300	501
2012	1,011	872	545	584	338	480
2013	1,007	952	598	561	388	495
2014	981	896	556	597	405	449
2015	1,048	878	525	588	413	410

Table S7. Relative contributions of six factors to changes in GHG emissions from interconnected grids of China during 2008–2015 (Unit: million tonnes of CO_2-e).

Decomposed factors	North China Grid	East China Grid	Central China Grid	Northeast China Grid	Northwest China Grid	Southern Power Grid
Fuel mix	78	30	21	19	7	18
Energy efficiency	-127	-85	-115	-53	-35	-73
Electricity structure	-49	-48	-40	-56	-24	-107
Electricity transmission structure	-2	-42	-5	2	0	-11
GDP	593	542	391	361	226	304
Electricity efficiency of GDP	-164	-165	-149	-118	32	-84
Total changes	**329**	**232**	**103**	**155**	**206**	**46**

Table S8. Relative contributions of six factors to changes in GHG emissions caused by electricity consumption of special provincial grids during 2008–2015 (Unit: million tonnes of CO_2-e).

Decomposed factors	Beijing	Shanghai	Hubei	Inner Mongolia	Xinjiang	Guangdong
Fuel mix	-3	14	1	5	2	1
Energy efficiency	-13	-21	-13	-28	-14	-27
Electricity structure	-6	-4	14	-22	-0	-34
Electricity transmission structure	-2	-12	-2	1	0	-11
GDP	42	50	46	154	63	169
Electricity efficiency of GDP	-18	-29	-22	-6	77	-55
Total changes	**1**	**-2**	**24**	**103**	**129**	**42**

Table S9. Relative contributions of factors to changes in emissions from the electricity system in China (by existing studies).

Study	Perspective	Spatial resolution and time period	Method	Factors and accumulated contribution (decrease (-)/increase (+) emissions)	The same as our study (Yes/No /Not covered (-))
Zhang et al. (2013)[1]	Electricity generation-side	National level (1991-2009)	LMDI	Energy efficiency of electricity generation (-)	Yes
				Electricity intensity of GDP (-)	Yes
				Electricity structure (i.e., share of thermal power generation) (-)	Yes
				CO_2 emissions coefficient of fossil fuel (-)	-
				Thermal power structure (i.e., fuel mix of thermal power) (+)	Yes
				GDP (+)	Yes
Zhou et al. (2014)[2]	Electricity generation-side	Six sub-national grids (2004-2010)	LMDI	Energy intensity of electricity generation (i.e., regional intensity effect) (-)	Yes
				Energy mix of electricity generation (i.e., fuel mix of thermal power) (-)	Yes
				Electricity share of sub-national grids (i.e., regional structure effect) (+)	-
				CO_2 emissions intensity of energy (+)	-
				Thermal electricity production (i.e., activity effect) (+)	-
Yan et al. (2016)[3]	Electricity generation-side	Six sub-national grids (2000-2012)	LMDI	Energy efficiency of GDP (-)	Yes
				Energy structure of thermal power generation (i.e., fuel mix) (-)	Yes
				GDP (+)	Yes
				Population, CO_2 emissions intensity of energy (+)	-
Liu et al. (2017)[4]	Electricity generation-side	Provincial grids (2000-2014)	LMDI	Energy intensity of thermal power generation (-)	Yes
				Fuel mix of thermal power (-)	Yes
				Electricity share of provincial grids (i.e., regional shift effect) (-)	-
				Clean power penetration (i.e., electricity structure) (-)	Yes
Ma et al. (2019)[5]	Electricity generation and consumption side	Sector level (2007,2012, 2015)	IO-SDA	Energy structure impacts (-)	Yes
				Technical impacts (i.e. generation efficiency) (-)	Yes
				Final use structure impacts (+)	-
				Final use level impacts (+)	Yes

References

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